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ADVANCING ENVIRONMENTAL QUALITY THROUGH INNOVATION AND GREEN ENTREPRENEURSHIP

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Abstract. This study investigates the relationships among green entrepreneurial activities, Green Techno-Environmental Innovations (GTEI) and environmental quality. Economic development and renewable energy consumption (CRE) are used as control variables to explore the phenomenon more comprehensively. Data are collected from 40 Organization for Economic Cooperation and Development (OECD) economies and analyzed using ordinary least squares regression models. The findings indicate that green entrepreneurship, GTEI and CRE enhance climate sustainability, whereas economic development leads to a deterioration in environmental quality. This study replaces GTEI with green technologies related to energy generation and production and the disposal of greenhouse gases individually and finds similar results, except for clean technologies in the production of goods. Green innovations linked to production processes which do not show a significant impact on environmental quality. This result arises because production processes lead to harmful emissions, which, in turn, lead to a deterioration in climate quality. This study provides crucial insights and policy implications for enhancing green entrepreneurial activities within OECD economies.

Keywords: green entrepreneurship, green technological innovation, environmental quality, renewable energy, production process patents.

JEL Classification: Q55, Q56, L26.

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1. Introduction

In recent years, environmental quality has emerged as a vital economic concern. Carbon emissions and greenhouse gases are key drivers of climate damage (Adams & Nsiah, 2019); thus, policies are needed that aim to reduce carbon emissions and global warming to achieve the United Nations' (UN) Sustainable Development Goals (SDGs; International Energy Agency, 2021). The UN's (United Nations, 2015) SDGs are slated to be achieved before 2030. These goals highlight the importance of Green Technological Innovations (GTEIs), green economic advancements, green consumption and production processes and affordable green-clean energy to address environmental changes. In recent years, reducing hazardous emissions has become the chief concern for many countries (Du et al., 2019). In this regard, the literature has comprehensively explored the link between energy consumption and economic development given the complex and dynamic nature of this relationship. Energy consumption, as a driver of economic growth, leads to an interdependence between energy availability and sustainable development (Beckerman, 1992). However, this interdependence introduces a trade-off between economic growth and environmental quality, and rapid growth has been shown to lead to environmental degradation (Ho et al., 2024). Thus, to balance this trade-off, a pressing need has emerged to promote the adoption of green technologies that lead to sustainable development (Wani et al., 2024).

Incorporating Green Entrepreneurship (GEnt) instead of traditional new ventures can better safeguard environmental quality and promote radical GTEIs (Shepherd & Patzelt, 2011). This integration promotes economic profits for climate-oriented entrepreneurs (Johnson & Schaltegger, 2020). However, such green ventures suffer from a lack of legitimacy and the liability of newness as perceived by stakeholders during their early stages (Maldonado-Bautista et al., 2023). To efficaciously navigate these perceptions, early-stage green entrepreneurs should develop dynamic and agile routines and processes (Demirel & Kesidou, 2019) and exceptional proficiencies (Knoppen & Knight, 2022). This can help them adapt and use their competencies and resources in response to environmental concerns.

GEnt exploits environmental and economic opportunities while potentially enabling green industrial revolutions (Cesinger et al., 2022). Therefore, GEnt can be viewed as a revolutionary agent for balancing economic viability without deteriorating environmental quality because green ventures provide climate-oriented norms to industries (Hummels & Argyrou, 2021) and help implement GTEIs (Trapp & Kanbach, 2021). GTEIs control the overuse of energy, reduce pollution and promote environmental and economic quality (Wang et al., 2021). Prior studies also suggest that green innovation strategies supported by green intellectual capital contribute positively to both economic and environmental performance sustainability (Wang & Juo, 2021). Moreover, GTEIs improve the production of green goods, enhance the generation of green energy and reduce greenhouse gas emissions, thereby promoting climate quality (Kazi et al., 2021). GTEIs enhance the growth of renewable energy during production and help use green resources to attain sustainable advancements (Wang et al., 2020). In this context, green innovations enhance environmental quality while fostering economic advancements, financial development and human well-being (OECD, 2021). Here, GEnt helps develop strategies to reduce hazardous emissions and enhances eco-environmental growth. GTEIs improve the supply chain, better utilize energy in production processes (Wiebe, 2022), preserve natural resources and reduce carbon emissions. Therefore, GTEIs contribute to economic, social and environmental advancements.

The member countries of the Organization for Economic Cooperation and Development (OECD) have incorporated green growth into their ecological performance evaluations, financial surveys, capital and technology market appraisals, green city programs and other national and global policy-monitoring efforts. Therefore, conventional entrepreneurial ventures and technological innovations lead to a deterioration of economic and environmental growth within OECD economies. However, it is unclear whether shifting to green growth will result in eco-environmental advancements in OECD economies (Verkaart et al., 2019). However, Barbier (2020) observes the long-term effects of economic growth on environmental sustainability and suggests that successful transitions in G20 countries arise from investing in feasible transitions that require a long-term commitment.

This study explores a nexus that is grounded in three theoretical perspectives: Ecological Modernization Theory (EMT), Schumpeterian innovation theory and the Porter hypothesis. The EMT posits that economic development and environmental sustainability are not conflicting goals, arguing that technological innovation can ensure a decoupling of environmental degradation and economic growth (Mol & Spaargaren, 2000). In the context of the current study, GTEIs provide an impetus to improve production efficiency and hence motivate this study's exploration of OECD countries that strive for carbon neutrality. Meanwhile, the Schumpeterian view emphasizes the role of entrepreneurs in driving economic transformation; this is captured in the current study via green entrepreneurship (Schumpeter, 2017), which provides economic disruption that enables a transition to green technologies that can be commercialized. Finally, the Porter hypothesis provides a unique take on the relationship between competitiveness, which is driven by well-designed regulations, and innovation (Porter & van der Linde, 1995). While this study does not directly consider regulation, the relationship between GTEIs and green entrepreneurship is rationalized by this perspective, especially within the context of OECD countries, where climate-related policies and incentives are institutionalized and widespread.

Further, this study is motivated by the need to analyse the multifaceted links between energy consumption and economic development, given the role of energy in promoting industrial growth, thereby leading to social well-being (Jorgenson et al., 2014). Significant challenges remain in achieving a balance between energy consumption and environmental sustainability while achieving economic growth. The European Union (EU), through the Renewable Energy Directive II and the European Green Deal, has taken a proactive approach to climate action, with the aim of achieving climate neutrality by 2050. This policy has been shown to have an influence beyond the EU, especially with countries with close ties to the EU (Rybski, 2023). The approach has evolved from a "market failure" (based on carbon pricing) model toward an integrated approach that involves sociotechnological changes coupled with procedural governance and social subsidies (Boasson & Tatham, 2022). The shift provides a need to shift toward increasing reliance on technological innovations that enable greater energy efficiency.

The interplay among technological innovations, green entrepreneurship and environmental quality is particularly interesting given the intrinsic link between access to clean and affordable energy and improved living standards (Wani et al., 2024; Weis & Nikolic, 2024). This interplay is critical for OECD countries, where the climate targets set forth via the EU directives remain a policy priority, leading to the need to balance economic growth with environmental preservation. For non-EU members, most do have similar emission targets but the degree of ambition, legal enforceability as well as mechanism for implementation may differ. Moreover, for OECD countries, adopting innovative technologies and solutions would bring about systemic changes in energy production and consumption in line with the target of achieving carbon neutrality by 2050.

In addition, OECD economies provide an ideal landscape for this study given its policy leadership; the literature has documented the role of regional authorities in achieving energy transition (Hu et al., 2022). In addition, the interplay between GTEI and green growth rely on government effectiveness in G7 countries (Yikun et al., 2023). Carbon emissions have reduced due to eco-innovations and are influenced by governance in the G7 countries (Aliani et al., 2024). In addition, regulations in G7 countries directly and indirectly reduce, via innovations, pollution (Nazir et al., 2023). The G7 countries' adoption of green energy and environmental policies have also been shown to reduce CO_2 emissions, further lending credence toward the importance of the carbon neutrality goals (Akram et al., 2023).

The current study focuses on OECD economies because these economies include developed and developing economies that are currently experiencing good economic trends and rapid globalization. These economies have developed shared approaches and some common strategies to cope with climate deterioration. The OECD economies have introduced incentives for private and public sector investments, enhanced environmental policies and increased investment in education and R&D. Production process innovations reduce the cost of production and improve quality (Nigg-Stock et al., 2023). Inventions in renewable energy consumption (CRE) and technologies to save energy are the key pillars to address climate mitigation challenges and are endogenous to achieving sustainable goals. Figure 1 shows the geographical distribution of CO_2 emissions, greenhouse gas emissions, CRE and the percentage of entrepreneurs who consider environmental impacts while making decisions: Figure 1a and Figure 1b illustrate the geographical distribution of CO_2 emissions and greenhouse gas emissions, respectively, while Figure 1c and Figure 1d present renewable energy consumption and green entrepreneurial activity across the sample economies.

The abovementioned discussion highlights the need to examine the impact of GEnt and GTEI on environmental quality in various economies. Figure 2 provide the GDP per capita of the countries included in the current study in view of the EMT discussed above. This is followed by the other 2 theoretical foundations of Schumpeterian view as well as Porter's hypothesis which is highlighted in Figure 3. Specifically, Figure 3 presents the distribution of climate change mitigation patents related to energy generation (GTIEG), production and processing of goods (GTIPG), and disposal of greenhouse gases (GTIDG) relative to renewable energy consumption across the sampled OECD economies, highlighting cross-country heterogeneity in green innovation activity and renewable energy adoption. This study contributes to the prevailing literature in the following ways: first, rare evidence has documented the influence of GEnt on environmental quality. Second, previous studies have documented the impact of technological innovations on climate quality and ignored the inclusion of GTEI, while GTEI can better cope with rising environmental deterioration. Third, this study is the first to investigate the impact of green innovations related to energy generation, production processes and the disposal of greenhouse gases on environmental quality. Fourth, most previous works have investigated the nexus of technological innovations and carbon emissions in the context of developed economies with the assumption that developing economies have limited innovations that are insufficient at affecting environmental quality. Therefore, the current study focuses on OECD economies that include developed and developing economies. Fifth, this study replaces GTEI with different green innovations for robustness checking. The outcomes would be helpful in developing policies for green ventures and industrial innovations to cope with environmental deterioration. Last, this study incorporates economic growth and CRE as

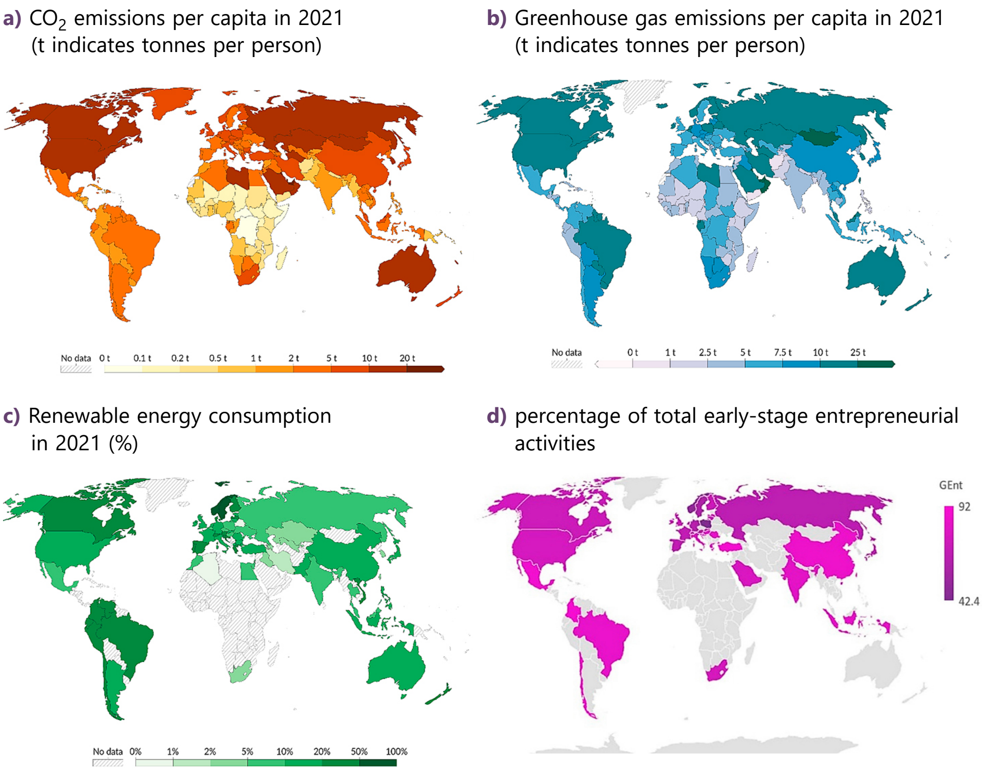

Figure 1. Environmental quality (CO_2 emissions), greenhouse gas emissions, CRE and percentage of entrepreneurs who consider environmental impacts. The detailed caption is given below each map. The change in shades indicates the severity of the respective variables (source: developed for study)

control variables and individually analyses the impact of GEnt and GTEI on climate quality in the presence of the control variables. The findings provide guidelines for early-stage green entrepreneurs to contribute to environmental quality.

The current study provides three incremental contributions to the literature. It addresses a gap in the literature by extending the work in a unified empirical framework via the integration of green entrepreneurship and green techno-environmental innovation. Secondly, the disaggregation of innovation into three patent classes captures the heterogeneity of environmental effects. Finally, it incorporates the GEM measure of green entrepreneurship which extends current work by providing evidence on its link to environmental quality in OECD countries.

The study discussion is sequenced as follows. The literature survey and hypothesis development are presented in the next section. Section 3 elaborates the methods used in the analysis and data description. Empirical results are provided in Section 4 along with a discussion of results in the light of findings inferred by previous studies. Section 5 concludes and presents policy implications that OECD economies could consider for excelling in environmental protection.

2. Literature review

The section connects GEnt and GTEIs with environmental quality. Although entrepreneurship enhances social and economic advancements, entrepreneurial ventures also theoretically have some adverse impacts. Traditional profit-driven entrepreneurship triggers economic advancements and therefore demands additional investments, resources and energy consumption. Thus, traditional entrepreneurship can lead to resource depletion, pollution (Venâncio & Pinto, 2020) and environmental degradation. Recent prevailing literature reveals an adverse nexus between conventional entrepreneurship and climate quality. Gu and Zheng (2021) observe the harmful effects of entrepreneurship on climate quality in China. Similar results are observed in Africa by Youssef et al. (2018); in emerging economies by Dhahri and Omri (2018); and in high-, medium- and low-income economies by Omri (2018). However, recent studies have observed negative impressions of necessity-based entrepreneurship on climate quality while detecting positive impressions of opportunity-based entrepreneurship on environmental sustainability (He et al., 2020; Dhahri et al., 2021; Aslam et al., 2022).

Studies argue that environment-oriented entrepreneurial ventures can better address environmental challenges; that is, they can preserve the ecosystem and enhance climate quality (York & Venkataraman, 2010; Shepherd & Patzelt, 2011). Meirun et al. (2020) argue that micro-level green environmental performance can be achieved through green entrepreneurial activities, which function as a hybrid mission and simultaneously achieve economic and environmental developments (Cesinger et al., 2022; Fischer et al., 2020). GEnt enhances climate-oriented industrial norms (Lüdeke-Freund, 2020; Hummels & Argyrou, 2021), contributing to GTEIs. Green ventures help entrepreneurs rethink sources of entrepreneurial opportunities, initiate new and adoptive business models and develop exclusive comparative advantages within dynamic and complex contexts, thereby achieving economic and environmental advancement (Muñoz & Cohen, 2018; Freudenreich et al., 2020). Additional research on dynamic capacities in the field of GEnt is needed to fully comprehend the association between green ventures and climate sustainability. Therefore, we propose the following hypothesis:

H1: *A positive connectedness exists between GEnt and environmental quality.*

Technological innovations have crucial impacts on entrepreneurship (Aslam et al., 2018) and environmental quality (Chang et al., 2023). According to Sun et al. (2019), GTEIs are crucial for addressing climate- and energy-related challenges. Such innovations encourage countries to optimize their use of renewable energy to minimize carbon emissions (Danish & Ulucak, 2021). However, the recent literature provides contradictory findings about the connection between technological innovation and climate change. Lin and Ma (2022) argue that GTEIs have uncertain influences on climate quality. Using modern Augmented Group Mean (AMG) and conventional Fully Modified Original Least Squared (FMOLS) models, Khan et al. (2020) observe that technological innovations reduce carbon emissions in BRICS economies. By contrast, among the same countries, Khattak et al. (2020) find a negative association between technological advancements and climate quality. Ganda (2019) discovers that R&D expenditures are negatively associated with carbon emissions in OECD economies, whereas technology patents are positively associated. Dauda et al. (2021) observe that between 1990 and 2016, technological innovations reduced hazardous emissions from South Africa, Mauritius and Egypt. Meanwhile, Godil et al. (2021) find that CRE and technological innovations mitigated carbon emissions in China over a longer period, from 1990 to 2018. Yikun et al. (2023) select G7 economies from 2000 to 2019 and explore the environmental dimensions of SDGs by applying the CS-ARDL model. They find that green growth and technological innovations enhance climate sustainability. Finally, Chang et al. (2023) investigate the influence of GTEIs on carbon emissions from 2003 to 2019. The authors collect data from 30 provinces of China; apply DID, SYS-GMM and SDM models; and find that GTEIs reduce carbon emissions.

The literature documents non-linear or mixed environmental effects arising from eco-innovation dependent on maturity of technology as well as absorptive capacity (Bădilă et al., 2024). Thus, it provides the basis for expecting non-uniform performance by green technologies across different categories. Circular-economy and innovation initiatives have also been shown to improve environmental outcomes, strengthening the argument on the need of institutional and policy conditions, which are of particular relevance to OECD members (Streimikis et al., 2024). Based on this discussion, we propose the following hypothesis:

H2: *A positive connectedness exists between GTEI and environmental quality.*

Using the STIRPAT model, Huang et al. (2021) argue that climate change mitigation patents related to energy generation do not have a significant role in reducing carbon emissions. Meanwhile, Kazi et al. (2021) find that GTEIs in green energy generation are negatively associated with climate quality. Naeem et al. (2023) argue that large investments are required to develop patents for renewable energy generation, such that environmental patents can ensure climate quality by generating clean energy. However, they argue that carbon emissions in neighboring economies also affect the climate of a country that is developed in terms of GTEIs related to energy generation (GTIEG).

The overarching expectation that GTEI leads to enhanced environmental quality is provided for in H2. H2a–H2c operationalise the three distinctive disaggregated patent categories: energy generation patents (GTIEG), production process patents as well as greenhouse gas disposal patents. Therefore, these are not distinct but extensions of the H2. Accordingly, we develop the following hypothesis:

H2a: *A positive connectedness exists between GTIEG and environmental quality.*

Ahmed et al. (2016) emphasize that technological innovations enhance renewable energy generation and reduce greenhouse gas emissions. Gu and Wang (2018) argue that R&D in greenhouse gas-mitigation technologies enhance climate sustainability. Among G20 economies, Erdoğan et al. (2020) observe that climate innovations reduce greenhouse gases and mitigate long-term carbon emissions. Between 1991 and 2017, Erdoğan (2021) examines 14 economies and finds that green technologies reduce industrial emissions. Meanwhile, Godil et al. (2021) find that higher levels of technological innovations lead to reduced levels of greenhouse gas emissions between 1990 and 2018. Alam et al. (2021) examine how investments in R&D and green technologies reduced carbon emissions in 30 OECD economies between 1996 and 2013. Hassan et al. (2024) find that GTEIs, renewable energy and nuclear energy mitigate greenhouse gas emissions and innovations related to the disposal of greenhouse gases improve environmental quality. Thus, we propose the following hypothesis:

H2b: *A positive connectedness exists between GTIDG and environmental quality.*

Green patents reduce energy consumption by production processes (Song et al., 2020; Wang & Zhu, 2020). Sustainable technological innovations drive climate sustainability by improving production process efficiency to provide climate-friendly goods and services (Cheng et al., 2021). Green process innovations reduce potential carbon emissions in production processes and halt environmental damage by firms (Luo et al., 2021). Over different time horizons, green technological and process innovations have been adopted by firms to reduce carbon emissions (Wang et al., 2021). Khattak et al. (2022) argue that from 1990 to 2018, GTEIs related to production processes enhanced environmental quality within G7 economies. Therefore, we propose that GTEIs related to the production of goods (GTIPG) reduce carbon emissions and enhance climate quality:

H2c: *A positive connectedness exists between GTIPG and environmental quality.*

From N11 economies, Shao et al. (2021) observe that CRE drives ecological sustainability. Appropriate halt strategies for global warming are required to tackle extreme environmental deterioration (Obobisa et al., 2022). While they pursue economic advancements, nations use fossil fuel energies. Such utilization releases hazardous gases into the environment, leading to climate deterioration. To cope with such issues, Li and Haneklaus (2022) argue that renewable energies and CRE are required to save the ecosystem from damage driven by economic advancement. Moreover, countries should drive economic advancement using renewable energy sources like ocean, solar and wind energies (De La Peña et al., 2022). Yuan et al. (2022) investigate the US economy and explore the connectedness between carbon emissions and CRE. The authors observe that carbon emission neutrality is driven by CRE within the US economy. Recently, economic advancements have been shown to trigger CO_2 emissions and disrupt the achievement of SDGs (Tang et al., 2022; Adjei et al., 2022). Using the environmental Kuznets curve, Kaya identity and Granger causality test, studies confirm non-linear dynamics between economic progress and climate quality (Yang et al., 2020; You et al., 2022; Liu et al., 2023). Based on conclusions from previous studies, we develop a nexus of CRE and economic growth with environmental quality in the following ways:

H3: *A positive connectedness exists between CRE and environmental quality.*

H4: *Economic growth (GDP) is significantly associated with environmental quality.*

Based on the Environmental Kuznets Curve theory, the impact of economic growth on environmental quality remains puzzling. Empirical priors have reported that for high-income OECD countries growth may lead to increased emissions based on the production scale effect. Therefore, H4 does not outright assume improvement in environmental quality. H4 is focused on a specific group of advanced economies and tests whether higher GDP is associated with CO_2 emissions.

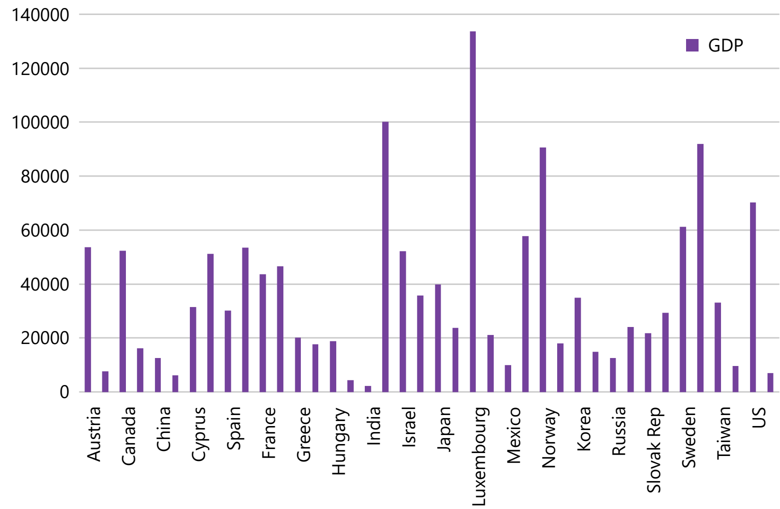

Figure 2. GDP per capita in sample economies

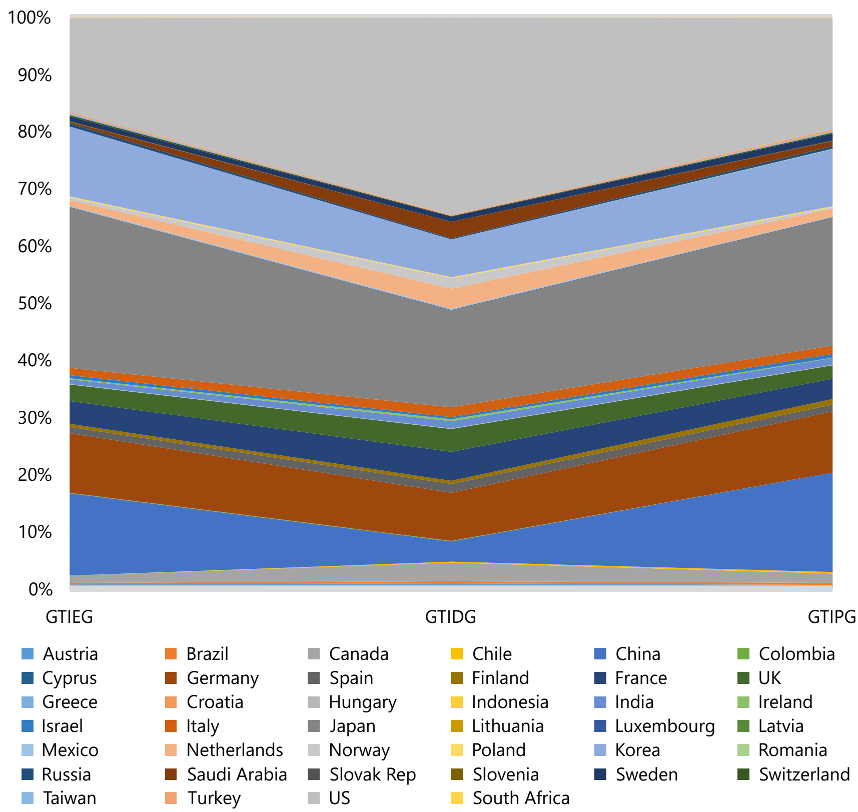

Figure 3. Distribution of climate change mitigation patents related to energy generation (GTIEG), production and processing of goods (GTIPG), and disposal of greenhouse gases (GTIDG) across sample OECD economies relative to renewable energy consumption (% of total final energy consumption)

Table 1. Summary of abbreviations, measurements and sources of data used for the variables

Variable	Abbreviations	Measurement	Sources
Dependent variable			
Green environmental growth	CO_2	Carbon emissions in metric tonnes per capita	World Development Indicators (WDI)
Independent variables			
Green entrepreneurship	GEnt	Percentage of total early-stage entrepreneurship activities	https://gemconsortium.org/
Green techno-environmental innovation	GTEI	Sum of all climate change mitigation patents	https://data-explorer.oecd.org/
Control variables			
Renewable energy consumption	CRE	Percentage of total final energy consumption	World Development Indicators (WDI)
Gross domestic production	GDP	Per capita GDP	World Development Indicators (WDI)
Replacement variables for GTEI			
GTEI related to energy generation, transmission or distribution	GTIEG	Climate change mitigation patents for energy generation	https://data-explorer.oecd.org/
GTEI in the production or processing of goods	GTIPG	Climate change mitigation patents for clean production and processes	https://data-explorer.oecd.org/
GTEI for the disposal of greenhouse gases	GTIDG	Climate change mitigation patents for the disposal of gases	https://data-explorer.oecd.org/

Note: WDI stands for World Development Indicators.

3. Data descriptions and empirical methods

3.1. Data and variables

This study collects data on environmental quality (measured through CO_2 emissions) from "Our World in Data" to validate the hypotheses developed in the previous section. Environmental quality is used as the dependent variable. The main independent variables are GTEIs (from different aspects) and GEnt. The data for green innovations are collected from "OECD.stat," which contains data for environmental change mitigation technologies related to energy generation and production processes and the disposal of greenhouse gases. Similarly, data for GEnt are obtained from the Global Entrepreneurship Monitor (GEM). GEnt is measured using the percentage of total early-stage entrepreneurial activities (TEAs). GEM is the largest worldwide data collection package that collects data on entrepreneurship activities from more than 2,000 adults per country. This data set considers the environmental implications of entrepreneurial activities. Neumann (2021) argues that this data set on GEnt is widely used in recent research to explore the macroeconomic impacts of green entrepreneurial activities on different environmental domains (e.g., Hechavarría et al., 2017; Hörisch et al., 2017; Hoogendoorn et al., 2020). GEM collects data on green economic growth and green social and entrepreneurial activities by allowing participants to allocate a total of 100 points: up to 50 to economic, 10 to social and 40 to green environmental aspects. The respondents assign scores based on their perception of the importance of ESG practices in their new ventures. Following Vuorio (2017), the current study argues that entrepreneurs are considered climate-oriented if they assign as many points to environmental orientation as they assign to economic orientation. GEM aggregates the individual-level data to the economic level and calls such respondents country-level green environmental entrepreneurs. Table 1 displays the abbreviations, measurements and sources of data for the variables used in the current study. The data on GEM are available for TEA from 2021 to 2023. However, the data for GTEIs are available for more than 50 countries on "OECD stat." from 1999 to 2020. Therefore, we use the data for GEnt (TEA) for the year 2021 to conduct the analysis. For green innovations, we forecast the data for 2021 based on previous years' data (1999–2020). The forecast data for 2021 provide the percentage change in the number of environmental change mitigation patents related to energy generation and production and the disposal of greenhouse gases. The forecast data include the effects of certain market conditions (Shahid & Sattar, 2017; Shahid et al., 2019). Therefore, we use a cross-sectional study with data from 40 OECD countries.

Table 2. Summary statistics

	CO_2	GEnt	GTEI	GDP	CRE	GTIEG	GTIDG	GTIPG
Mean	6.011790	74.52250	462.9294	36,558.67	22.43025	305.7967	9.490458	147.6422
Median	5.080661	75.55000	55.53999	29,697.46	18.64500	33.66621	0.997678	17.16929
Maximum	14.26659	92.00000	4,839.081	133,590.1	61.29000	3,451.993	131.2445	1,322.769
Minimum	1.552259	42.40000	1.612799	2,238.127	0.060000	0.997983	0.000000	0.262500
Std. Dev.	3.308079	11.79490	1,048.234	29,344.80	14.18543	710.2712	23.11488	324.5780

3.2. Empirical approach

Given the cross-country nature of this study, we develop an econometric model based on Ordinary Least Squares (OLS) regression models, which is the most common method used in cross-country analysis (e.g., Albulescu & Draghici, 2016; Ateeq et al., 2019; He et al., 2020; Méndez-Picazo et al., 2021). Environmental quality is proxied by CO_2 emissions per capita in metric tonnes. In cross-sectional studies, carbon emissions have been widely used to measure environmental quality (e.g., Omri, 2018; Dhahri & Omri, 2018; He et al., 2020) because CO_2 emission data are available for nearly all countries (ben Youssef et al., 2018).

Given the different techniques that have been used in environmental studies, the current study adopts the OLS approach because of the nature of the dataset, which is cross-sectional. The nature of the data hinders reliance on panel techniques such as fixed effects or random effects. This is in line with empirical priors which opt for OLS (Albulescu & Draghici, 2016; He et al., 2020). Thus, the interpretation of estimates leans toward associations rather than pure causal effects. In view of this, we acknowledge that forecasting of innovation variables introduces measurement uncertainty and therefore explicitly recognize this limitation. We use the following regression model to estimate the impact of GEnt and GTEI on environmental quality, measuring GTEI with green patents registered for environmental management in OECD economies as follows:

$$CO_{2t} = \lambda_0 + \lambda_1 GEnt_i + \lambda_2 GTEI_i + e_i, \tag{1}$$

where, λ_0 is the intercept, CO_2, the dependent variable represents the environmental quality (measured through carbon emissions) and i represents the country, $GEnt_i$ denotes green entrepreneurship, $GTEI_i$ denotes green techno-environmental innovation and e_i is the error term. CRE and GDP are used as control variables and presented in the econometric model as follows:

$$CO_{2t} = \lambda_0 + \lambda_1 GEnt_i + \lambda_2 GTEI_i + \lambda_3 CRE_i + \lambda_4 GDP_i + e_i, \tag{2}$$

where, λ_0 is the intercept, CO_2, the dependent variable, represents the environmental quality (measured through carbon emissions) and i represents the country, $GEnt_i$ is green entrepreneurship, $GTEI_i$ is green techno-environmental innovation, CRE_i is the consumption of renewable energy, GDP_i is gross domestic product per capita and e_i is the error term.

We measure GTEI with green patents registered for environmental management in OECD economies. For robustness checks, we replace GTEI with three different environmental mitigation patents: (i) climate change mitigation technologies related to energy generation, transmission or distribution (GTIEG); (ii) climate change mitigation technologies in the production or processing of goods (GTIPG); and (iii) technologies for disposing greenhouse gases (GTIDG). Therefore, we measure the impact of each type of innovation separately using the equations below:

$$CO_{2t} = \lambda_0 + \lambda_1 GEnt_i + \lambda_2 GTIEG_i + e_i, \tag{3}$$

where, λ_0 is the intercept, CO_2, the dependent variable, represents the environmental quaty (measured through carbon emissions) and i represents the country, $GEnt_i$ is green entrepreneurship, $GTIEG_i$ is green techno-environmental innovation related to energy generation and e_i is the error term:

$$CO_{2t} = \lambda_0 + \lambda_1 GEnt_i + \lambda_2 GTIPG_i + e_i, \tag{4}$$

where, λ_0 is the intercept, CO_2, the dependent variable, represents the environmental qualeasured through carbon emissions) and i represents the country, $GEnt_i$ is green entreeneurship, $GTIEG_i$ is green techno-environmental innovation in the production or processing of goods and e_i is the error term:

$$CO_{2t} = \lambda_0 + \lambda_1 GEnt_i + \lambda_2 GTIDG_i + e_i, \tag{5}$$

where, λ_0 is the intercept, CO_2, the dependent variable, represents the environmental quali (measured through carbon emissions) and i represents the country, $GEnt_i$ is green entrepreneurship, $GTIDG_i$ is green techno-environmental in technologies for disposal of greenhouse gases and e_i is the error term.

To enhance the impact of three GTEIs, we add each GTEI along with control variables. The calculations are presented in the following equations:

$$CO_{2t} = \lambda_0 + \lambda_1 GEnt_i + \lambda_2 GTIEG_i + \lambda_3 CRE_i + \lambda_4 GDP_i + e_i, \tag{6}$$

where, λ_0 is the intercept, CO_2, the dependent variable, represents the environmental quality (measured through carbon emissions) and i represents the country, $GEnt_i$ is green entrepreneurship, $GTIEG_i$ is green techno-environmental innovation related to energy generation, CRE_i is the consumption of renewable energy, GDP_i is gross domestic product per capita and e_i is the error term:

$$CO_{2t} = \lambda_0 + \lambda_1 GEnt_i + \lambda_2 GTIEG_i + \lambda_3 GTIPG_i + \lambda_4 CRE_i + \lambda_5 GDP_i + e_i, \tag{7}$$

where, λ_0 is the intercept, CO_2, the dependent variable, represents the environmental quality (measured through carbon emissions) and i represents the country, $GEnt_i$ is green entrepreneurship, $GTIEG_i$ is green techno-environmental innovation related to energy generation, $GTIPG_i$ is green techno-environmental in technologies for disposal of greenhouse gases, CRE_i is the consumption of renewable energy, GDP_i is gross domestic product per capita and e_i is the error term:

$$CO_{2t} = \lambda_0 + \lambda_1 GEnt_i + \lambda_2 GTIEG_i + \lambda_3 GTIPG_i + \lambda_4 GTIDG_i + \lambda_5 CRE_i + \lambda_6 GDP_i + e_i, \tag{8}$$

where, λ_0 is the intercept, CO_2, the dependent variable, represents the environmental quality (measured through carbon emissions) and i represents the country, $GEnt_i$ is green entrepreneurship, $GTIEG_i$ is green techno-environmental innovation related to energy generation, $GTIPG_i$ is green techno-environmental in the production or processing of goods, $GTIDG_i$ is green techno-environmental in technologies for disposal of greenhouse gases, CRE_i is the consumption of renewable energy, GDP_i is gross domestic product per capita and e_i is the error term.

Taows the summary statistics for the variables used in this study, where the mean values are 6.01, 74.52, 462.92, 36,558.67, 22.43, 305.7, 9.49 and 147.64 for carbon emissions, GEnt, GTEI, GDP, CRE, GTIEG, GTIDG and GTIPG, respectively.

Table 3. Correlations

	CO_2	GENT	GTEI	GDP	CRE	GTIEG	GTIDG	GTIPG
CO_2	1							
GENT	−0.2063***	1						
GTEI	−0.2315**a	0.1392**a	1					
GDP	0.4013**	0.4143**	0.0878***	1				
CRE	−0.3923**	0.0185***	0.2685**	0.1243**	1			
GTIEG	−0.2084**a	0.1502**a	0.9973***a	0.0825**a	0.2676**a	1		
GTIDG	−0.3741**a	0.1299***a	0.7988***a	0.2169***a	0.2330***a	0.7714***a	1	
GTIPG	−0.2651**a	0.1115**a	0.9901***a	0.0876**a	0.2648***a	0.9776***a	0.8204***a	1

Note: The level of confidence is given as follows: *** indicates significance at 1%, ** indicates significance at 5% and * indicates significance at 1%. "a" indicates variables that are not used in a model simultaneously.

4. Empirical findings

4.1. Regression analysis

We first perform a correlation analysis to reveal the multicollinearity between the study variables (Table 3). Carbon emissions have a negative association with GEnt, GTEI and CRE, whereas they have a positive association with GDP. These associations indicate that GEnt, GTEI and CRE reduce carbon emissions and enhance environmental quality. Table 3 shows that GEnt has a positive association with all the variables, which implies that green entrepreneurs consider GTEIs. We find no multicollinearity problem in the data because the values of the Variance Inflation Factor (VIF) are below 10 (VIF max = 2.18).

Table 4. OLS regression results

Models	Model-1	Model-2
Variable	Coefficient	Coefficient
C	9.419***	6.786**
GENT	−0.0497**	−0.0615**
GTEI	−0.0653**	−0.0238***
GDP		0.00495***
CRE		−0.09959**
R^2	0.563	0.634
Durbin–Watson	2.0067	2.0104
VIF max	1.03	1.07
F statistic	7.16***	12.67***
Schwarz criterion	5.393658	5.21134
Observations	40	40

Note: The level of confidence is given as follows: *** indicates significance at 1%, ** indicates significance at 5% and * indicates significance at 1%. An addended "a" indicates variables that are not simultaneously used in a model.

For Eqs. (1)–(2), this study presents the outcomes of OLS regression through Model-1 and Model-2 in Table 4. Model-1 incorporates the main independent variables. Table 4 shows that GEnt has a negative and significant (−0.0497**) association with carbon emissions. This finding indicates that an increase in GEnt activities reduces carbon emissions, which enhances environmental quality. The results are the same, but with a stronger coefficient (−0.0615**), when control variables are considered (Model-2). Therefore, H01, which states that a positive connectedness exists between GEnt and environmental quality, is accepted. The outcomes of this study are in line with the findings of recent studies finding that GEnt positively affects climate quality (He et al., 2020; Dhahri et al., 2021; Aslam et al., 2022; Cesinger et al., 2022). Similarly, GTEI has a negative-significant (−0.0653**) impact on carbon emissions, which means that such innovations reduce carbon emissions and enhance environmental quality that contributes to sustainable development (Chien, 2023). The connectedness between GTEI and carbon emissions is the same when the control variables are incorporated in the model (Model-2). Thus, H02, which states that a positive connectedness exists between GTEI and environmental quality, is accepted. The results are similar to the findings of Yikun et al. (2023) and Chang et al. (2023), who observe similar connectedness of GTEI and climate sustainability from G7 economies and China, respectively. Thus, to promote sustainable development, government incentives such as subsidies would need to be directed toward adoption of clean and green technology (Kun, 2024). The rationale would be guided by the potential as documented in our empirical priors (Streimikiene & Mikalauskiene, 2023).

Model-2 incorporates the control variables (CRE and GDP) used in this study. CRE has negative connections with carbon emissions, which indicates that such consumptions reduce carbon emissions and enhance environmental quality. Thus, H03, which states that a positive connectedness exists between CRE and environmental quality, is supported. Such findings are parallel with the outcomes of recent studies (Shao et al., 2021; Obobisa et al., 2022). Table 4 shows that GDP has a positive connectedness with carbon emissions, which implies that growth in GDP causes an upsurge in carbon emissions. These results reveal that countries under study have gained economic growth at the cost of environmental deterioration. Accordingly, H04, which states that a positive connectedness exists between GDP growth and environmental quality, is rejected. Tang et al. (2022) and Adjei et al. (2022) also find adverse impacts of economic advancements on environmental sustainability. While GDP growth is associated with an adverse impact on the environment, financial globalization enhances domestic financial markets, leading to increased green innovation (Chen et al., 2023). Future studies should investigate this factor further as a logical progression from our findings, enabling a consideration of the influence of economic risk on the development of a green economy (Lee et al., 2023). Additional macro level factors, such as the level of economic maturity and the degree of diffusion of innovation, should also be included in future frameworks (Banelienė & Strazdas, 2023).

The evidence indicates a negative association between GTEI and CO2 emissions, which is reflective of OECD countries characterized by a mature innovation ecosystem. The diffusion of clean technologies would be enhanced through greater investment in R&D, capacity to absorb as well as regulatory pressure. On the other hand, the insignificant effect of GTIPG is aligned with non-linear or delayed environmental benefits arising from process innovations (Ahmad et al., 2021). It is likely that patents in the real-world production would lead to increased energy consumption at the initial stages before efficiency gains are captured.

Alternatively, environmental improvements could inherently lead to enhanced innovations. It is likely firms would be encouraged to pursue additional green patents due to a stronger environmental governance as well as a cleaner energy mix as observed in recent evidence from OECD and Central European studies (Streimikis et al., 2024). While the current study does not specifically investigate feedback effects, the two-way relationship provides a rationale in interpreting the results as well as informing direction of future research.

The results show heterogeneity across OECD members as indicated by the magnitude of the coefficients. It can be observed that in countries with more stringent regimes, stronger innovation systems and larger penetration of renewables capture the greater benefits of GTEI relative to countries with lower R&D intensity or slower pace of adoption of clean technologies.

4.2. Robustness analysis

To confirm the robustness of the principal findings, we employ six different models by incorporating replacement variables (Eqs. (3)–(8)). All models reflect a negative association of GEnt with carbon emissions. The findings are consistent with the results obtained in the initial OLS regression. Specifically, the impact of GEnt remains even after different technological innovation variables are incorporated in the model.

Table 5. Robustness outcomes with replacement variables for GTEI

Models	Model-1	Model-2	Model-3	Model-4	Model-5	Model-6
Variable	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient
C	9.495231**	8.884049***	9.383193***	6.882284**	7.390633**	8.190424**
GENT	−0.050212**	−0.044982**	−0.050191***	−0.006645**	−0.012537**	−0.024080**
GTIEG	−0.0845***			−0.000244**	−0.001002***	−0.005434*
GTIDG		−0.050564**			−0.051025**	−0.024481**
GTIPG			0.02499			0.01133
GDP				4.97E−05***	4.22E−05***	4.28E−05**
CRE				−0.10111***	−0.0966***	−0.09772***
R^2	0.363	0.465282	0.539	0.674	0.6107	0.750064
Durbin–Watson	2.018	2.042	2.006	2.001	2.091	2.1022
VIF max	1.044	1.093	1.354	1.096	1.359	1.453
F statistic	3.99**	3.663**	3.835**	4.98***	4.739178***	4.501166***
Schwarz criterion	5.404259	5.301299	5.374462	5.215497	5.229801	5.252895
Observations	40	40	40	40	40	40

Note: The level of confidence is given as follows: *** indicates significance at 1%, ** indicates significance at 5% and * indicates significance at 1%. An addended “a” indicates variables that are not simultaneously used in a model.

In Model-1, Model-2 and Model-3 (Table 5), GTEI is replaced with GTIEG, GTIDG and GTIPG, respectively. GTIEG in Model-1 is negatively and significantly associated with reducing carbon emissions. Therefore, GTIEG is favorable for environmental quality. Similar findings are observed with GTIDG in Model-1. Therefore, GTIEG and GTIDG support the results obtained with GTEI (obtained through the original OLS regression model presented in Table 4) and confirm the robustness of the primary conclusions. Thus, H02a and H02b are accepted. These findings indicate that green technologies that are related to goods production reduce climate quality; however, the association is nonsignificant. Therefore, the findings partially reject H02c. Subsequently, this study employs GTIEG (Model-4), GTIEG and GTIDG (Model-5) and GTIEG, GTIDG and GTIPG (Model-6) along with the control variables, as discussed in Eqs. (6)–(8). The findings confirm the robustness of the results. Based on the findings, regulatory policies from regulators, such as green credits, that foster enterprise green innovation warrant further exploration (Fang et al., 2024), especially because regulators’ focus on default costs and pollution taxes tends to accelerate green innovation (Zhang et al., 2024). Carbon emissions are not a national but a global challenge. Thus, green entrepreneurs’ technological advancements can better enhance environmental sustainability (Neumann, 2022). In addition, the literature provides evidence of a potential among OECD countries to shift toward sustainable development driven by human development, in line with the findings of this study supporting the impact of entrepreneurial activities (Yumashev et al., 2020). Furthermore, non-linear approaches such as the ANFIS model (Hussain et al., 2020) provide the flexibility needed to better model the intricate relationships explored in this study.

5. Conclusions, policy implications and recommendations

This study addresses environmental challenges under the umbrella of GEnt and GTEI, clarifying the impacts of GTIEG, goods production and greenhouse gas disposal. Prevailing studies infer that conventional entrepreneurship and technological innovations enhance economic advancement while reducing environmental quality. However, this study proposes that GEnt and GTEI are positively associated with environmental sustainability. This study incorporates GDP and CRE in connection with environmental sustainability and uses an OLS regression model to uncover the proposed connections using data from 40 OECD economies.

The findings confirm that green entrepreneurs consider climate challenges in their decision-making; therefore, green entrepreneurial activities enhance environmental quality. Similarly, GTEIs polish environmental quality by reducing carbon emissions. The OLS regression models indicate that GTEIs and CRE mitigate hazardous emissions, thereby promoting climate quality. The results align with the literature, which indicates that green innovation contributes toward sustainable development. Specifically, economic growth mitigates environmental quality because the upsurge in GDP leads to the deterioration of environmental sustainability. Therefore, the economic growth in OECD economies may offset the possible benefits of green technologies and GEnt. To verify the robustness of the results, GTEI is replaced in the regression models with climate mitigation technologies related to clean energy generation, goods production and greenhouse gas disposal. However, the results remain similar, except for the role of clean technologies in the production of goods, which do not significantly improve climate quality. This is likely because production processes lead to harmful emissions at the initial stages that reduce environmental sustainability where as efficiency gains are only realised in the long run. Overall, increased percentages of GEnt and green innovation promote sustainable development by fostering an environment that simultaneously benefits social and economic objectives.

Based on these findings, this study proposes the following policy recommendations: (i) governments and policy makers in OECD economies should encourage entrepreneurs to create and exploit green business opportunities through policies such as green credit, which enhance enterprise green innovation. This can be achieved by encouraging cooperation among stakeholders through policies centered on default costs and pollution taxes, given their role in accelerating green innovation. (ii) Academicians should focus on conducting applied research about the development of innovative goods and services to cope with environmental challenges. (iii) Governments should incentivize and subsidize clean and green technology sectors, given that adopting such technologies tends to lead to sustainable economic development. (iv) OECD economies should enhance green entrepreneurial activities across all sectors to transform traditional approaches to green innovations. This task can be performed through financial incentives. (v) Managers should consider environmental, social and economic perspectives in entrepreneurial activities.

This study also has some limitations that should be acknowledged. This study is based on a limited number of observations because only a limited data set was available on GEM. Future researchers should establish a comprehensive index for measuring green entrepreneurial activities. Furthermore, this study covers only the GTEIs available at (https://data-explorer.oecd.org/). Future works should consider all registered environmental patents (agricultural, household, industrial, transportation, clean water and construction). Moreover, the construction of the GTEI variable utilized forecasted 2021 values based on country-specific simple linear regressions. Although a consistent approach was adopted across all 40 countries, the reliability of the forecasts varied across countries, which could introduce measurement errors into the variable. To enhance the robustness of the findings, future studies could consider nonlinear models across countries or account for institutional heterogeneity across the sample. To further address the limitations of the current study, future studies should incorporate panel data estimations that allow for dynamic analysis to consider changes over time. Panel data estimators provide more robust causal inferences, thereby leading to more relevant policymaking insights.

In addition, a promising avenue for future research would be to include the impact of financial globalization, which has been found to enhance domestic financial markets and lead to greater green innovation. Further research may consider comparing countries, regions and provinces given that the literature documents economic risk playing a crucial part in encouraging green economy development, and such development persists over time. Additionally, to avoid omitted variable bias, future research should explore macroeconomic control variables because the current study only incorporates the most popular control variables. Mediation and moderation analysis may also be useful to capture the real impacts of the variables used in the current study. Further, instead of using secondary data, survey-based data may provide a comprehensive analysis of GEnt, green innovations and environmental quality. Future researchers should explore these associations under specific market conditions and explore their interplay using a time-lag structure. Finally, future studies could incorporate different levels of maturity in the economies and diffusion of innovation, thereby providing a more meaningful analysis to encourage economic growth.

References

Ahmad, M., Khan, Z., Rahman, Z. U., Khattak, S. I., & Khan, Z. U. (2021). Can innovation shocks determine CO_2 emissions (CO_2e) in the OECD economies? A new perspective. *Economics of Innovation and New Technology*, *30*(1), 89–109. https://doi.org/10.1080/10438599.2019.1684643

Adams, S., & Nsiah, C. (2019). Reducing carbon dioxide emissions: Does renewable energy matter? *Science of the Total Environment*, *693*, Article 133288. https://doi.org/10.1016/j.scitotenv.2019.07.094

Adjei, M., Song, H., Cai, X., Nketiah, E., Obuobi, B., & Adu-Gyamfi, G. (2022). Globalization and economic complexity in the implementation of carbon neutrality in Africa's largest economies. *Sustainable Energy Technologies and Assessments*, *52*, Article 102347. https://doi.org/10.1016/j.seta.2022.102347

Ahmed, A., Uddin, G. S., & Sohag, K. (2016). Biomass energy, technological progress and the environmental Kuznets curve: Evidence from selected European countries. *Biomass and Bioenergy*, *90*, 202–208. https://doi.org/10.1016/j.biombioe.2016.04.004

Akram, R., Ibrahim, R. L., Wang, Z., Adebayo, T. S., & Irfan, M. (2023). Neutralizing the surging emissions amidst natural resource dependence, eco-innovation, and green energy in G7 countries: Insights for global environmental sustainability. *Journal of Environmental Management*, *344*, Article 118560. https://doi.org/10.1016/j.jenvman.2023.118560

Alam, M. S., Apergis, N., Paramati, S. R., & Fang, J. (2021). The impacts of R&D investment and stock markets on clean-energy consumption and CO2 emissions in OECD economies. *International Journal of Finance & Economics*, *26*(4), 4979–4992. https://doi.org/10.1002/ijfe.2049

Albulescu, C. T., & Drăghici, A. (2016). Entrepreneurial activity and national innovative capacity in selected European countries. *The International Journal of Entrepreneurship and Innovation*, *17*(3), 155–172. https://doi.org/10.1177/1465750316655902

Aliani, K., Borgi, H., Alessa, N., Hamza, F., & Albitar, K. (2024). The impact of green innovation and renewable energy on CO_2 emissions in G7 nations. *Heliyon*, *10*(10), Article e31142. https://doi.org/10.1016/j.heliyon.2024.e31142

Aslam, S., Shahid, M. N., & Aftab, F. (2022). Role of entrepreneurial orientation in SMEs global performance: Testing marketing strategies and technological orientation as mediators. *Journal of Marketing Strategies*, *4*, 173–201.

Aslam, S., Shahid, M. N., Qureshi, M. H., & Qureshi, A. M. (2018). Investigating innovativeness and emotional intelligence as mediator to explore entrepreneurial marketing strategy focused on firm performance: A case in Pakistan. *Journal of Applied Environmental and Biological Sciences*, *8*, 48–60.

Ateeq, A., Riaz, A., Tahir, S. H., Shahid, M. N., & Ullah, R. M. (2019). The association among risk management, financial performance, financing decision and investment decision based on firm size: An empirical investigation of non-financial firms listed at Pakistan stock exchange. *Pacific Business Review International*, *11*, 29–38.

Bădilă, M. I., Bârsan, G., & Cioca, L. I. (2024). Model for the prediction of performance with eco-innovation capability development criteria: A military logistic regression analysis. *Polish Journal of Management Studies*, *29*(2), 87–120. https://doi.org/10.17512/pjms.2024.29.2.05

Barbier, E. B. (2020). Greening the post-pandemic recovery in the G20. *Environmental and Resource Economics*, *76*, 685–703. https://doi.org/10.1007/s10640-020-00437-w

Banelienė, R., & Strazdas, R. (2023). Green innovation for competitiveness: Impact on GDP growth in the European Union. *Contemporary Economics*, *17*(1), 92–108. https://doi.org/10.5709/ce.1897-9254.501

Beckerman, W. (1992). *Economic development and the environment*: *Conflict of complementarity?* (Working Paper No. 961). The World Bank.

Boasson, E. L., & Tatham, M. (2023). Climate policy: From complexity to consensus? *Journal of European Public Policy*, *30*(3), 401–424. https://doi.org/10.1080/13501763.2022.2150272

Cesinger, B., Vallaster, C., & Müller, J. M. (2022). The ebb and flow of identity: How sustainable entrepreneurs deal with their hybridity. *European Management Journal*, *40*(1), 77–89. https://doi.org/10.1016/j.emj.2021.04.003

Chang, K., Liu, L., Luo, D., & Xing, K. (2023). The impact of green technology innovation on carbon dioxide emissions: The role of local environmental regulations. *Journal of Environmental Management*, *340*, Article 117990. https://doi.org/10.1016/j.jenvman.2023.117990

Chen, R., Ramzan, M., Hafeez, M., & Ullah, S. (2023). Green innovation-green growth nexus in BRICS: Does financial globalization matter? *Journal of Innovation & Knowledge*, *8*(1), Article 100286. https://doi.org/10.1016/j.jik.2022.100286

Cheng, C., Ren, X., Dong, K., Dong, X., & Wang, Z. (2021). How does technological innovation mitigate CO_2 emissions in OECD countries? Heterogeneous analysis using panel quantile regression. *Journal of Environmental Management*, *280*, Article 111818. https://doi.org/10.1016/j.jenvman.2020.111818

Chien, F. (2023). The impact of green investment, eco-innovation, and financial inclusion on sustainable development: Evidence from China. *Engineering Economics*, *34*(1), 17–31. https://doi.org/10.5755/j01.ee.34.1.32159

Danish, & Ulucak, R. (2021). Renewable energy, technological innovation and the environment: A novel dynamic auto-regressive distributive lag simulation. *Renewable and Sustainable Energy Reviews*, *150*, Article 111433. https://doi.org/10.1016/j.rser.2021.111433

Dauda, L., Long, X., Mensah, C. N., Salman, M., Boamah, K. B., Ampon-Wireko, S., & Dogbe, C. S. K. (2021). Innovation, trade openness and CO_2 emissions in selected countries in Africa. *Journal of Cleaner Production*, *281*, Article 125143. https://doi.org/10.1016/j.jclepro.2020.125143

De La Peña, L., Guo, R., Cao, X., Ni, X., & Zhang, W. (2022). Accelerating the energy transition to achieve carbon neutrality. *Resources*, *Conservation and Recycling*, *177*, Article 105957. https://doi.org/10.1016/j.resconrec.2021.105957

Demirel, P., & Kesidou, E. (2019). Sustainability-oriented capabilities for eco-innovation: Meeting the regulatory, technology, and market demands. *Business Strategy and the Environment*, *28*(5), 847–857. https://doi.org/10.1002/bse.2286

Dhahri, S., & Omri, A. (2018). Entrepreneurship contribution to the three pillars of sustainable development: What does the evidence really say? *World Development*, *106*, 64–77. https://doi.org/10.1016/j.worlddev.2018.01.008

Dhahri, S., Slimani, S., & Omri, A. (2021). Behavioral entrepreneurship for achieving the sustainable development goals. *Technological Forecasting and Social Change*, *165*, Article 120561. https://doi.org/10.1016/j.techfore.2020.120561

Du, K., Li, P., & Yan, Z. (2019). Do green technology innovations contribute to carbon dioxide emission reduction? Empirical evidence from patent data. *Technological Forecasting and Social Change*, *146*, 297–303. https://doi.org/10.1016/j.techfore.2019.06.010

Erdoğan, S. (2021). Dynamic nexus between technological innovation and building sector carbon emissions in the BRICS countries. *Journal of Environmental Management*, *293*, Article 112780. https://doi.org/10.1016/j.jenvman.2021.112780

Erdoğan, S., Yıldırım, S., Yıldırım, D. Ç., & Gedikli, A. (2020). The effects of innovation on sectoral carbon emissions: Evidence from G20 countries. *Journal of Environmental Management*, *267*, Article 110637. https://doi.org/10.1016/j.jenvman.2020.110637

Fang, X., Liu, M., & Li, G. (2024). Can the green credit policy promote green innovation in enterprises? Empirical evidence from China. *Technological and Economic Development of Economy*, *30*(4), 899–932. https://doi.org/10.3846/tede.2024.20497

Fischer, D., Brettel, M., & Mauer, R. (2020). The three dimensions of sustainability: A delicate balancing act for entrepreneurs made more complex by stakeholder expectations. *Journal of Business Ethics*, *163*, 87–106. https://doi.org/10.1007/s10551-018-4012-1

Freudenreich, B., Lüdeke-Freund, F., & Schaltegger, S. (2020). A stakeholder theory perspective on business models: Value creation for sustainability. *Journal of Business Ethics*, *166*, 3–18. https://doi.org/10.1007/s10551-019-04112-z

Ganda, F. (2019). The impact of innovation and technology investments on carbon emissions in selected Organisation for Economic Co-operation and Development countries. *Journal of Cleaner Production*, *217*, 469–483. https://doi.org/10.1016/j.jclepro.2019.01.235

Godil, D. I., Yu, Z., Sharif, A., Usman, R., & Khan, S. A. R. (2021). Investigate the role of technology innovation and renewable energy in reducing transport sector CO_2 emission in China: A path toward sustainable development. *Sustainable Development*, *29*(4), 694–707. https://doi.org/10.1002/sd.2167

Gu, G., & Wang, Z. (2018). Research on global carbon abatement driven by R&D investment in the context of INDCs. *Energy*, *148*, 662–675. https://doi.org/10.1016/j.energy.2018.01.142

Gu, W., & Zheng, X. (2021). An empirical study on the impact of sustainable entrepreneurship: Based on the environmental Kuznets model. *Journal of Business Research*, *123*, 613–624. https://doi.org/10.1016/j.jbusres.2020.10.011

Hassan, S. T., Danish, D., Baloch, M. A., Bui, Q., & Khan, N. H. (2024). The heterogeneous impact of geopolitical risk and environment-related innovations on greenhouse gas emissions: The role of nuclear and renewable energy in the circular economy. *Gondwana Research*, *127*, 144–155. https://doi.org/10.1016/j.gr.2023.08.016

He, J., Nazari, M., Zhang, Y., & Cai, N. (2020). Opportunity-based entrepreneurship and environmental quality of sustainable development: A resource and institutional perspective. *Journal of Cleaner Production*, *256*, Article 120390. https://doi.org/10.1016/j.jclepro.2020.120390

Hechavarría, D. M., Terjesen, S. A., Ingram, A. E., Renko, M., Justo, R., & Elam, A. (2017). Taking care of business: The impact of culture and gender on entrepreneurs' blended value creation goals. *Small Business Economics*, *48*, 225–257. https://doi.org/10.1007/s11187-016-9747-4

Ho, T. L., Nguyen, B.-C. X., & Ho, T. H. (2024). Is there a trade-off between economic growth, foreign direct investment, international trade and environmental degradation? A comparison between Asian developed and developing countries. *Foreign Trade Review*, *61*, 53–78. https://doi.org/10.1177/00157325231214319

Hoogendoorn, B., van der Zwan, P., & Thurik, R. (2020). Goal heterogeneity at start-up: Are greener start-ups more innovative? *Research Policy*, *49*(10), Article 104061. https://doi.org/10.1016/j.respol.2020.104061

Hörisch, J., Kollat, J., & Brieger, S. A. (2017). What influences environmental entrepreneurship? A multilevel analysis of the determinants of entrepreneurs' environmental orientation. *Small Business Economics*, 48(1), 47–69. https://doi.org/10.1007/s11187-016-9765-2

Hu, K., Sinha, A., Tan, Z., Shah, M. I., & Abbas, S. (2022). Achieving energy transition in OECD economies: Discovering the moderating roles of environmental governance. *Renewable and Sustainable Energy Reviews*, *168*, Article 112808. https://doi.org/10.1016/j.rser.2022.112808

Huang, J., Li, X., Wang, Y., & Lei, H. (2021). The effect of energy patents on China's carbon emissions: Evidence from the STIRPAT model. *Technological Forecasting and Social Change*, *173*, Article 121110. https://doi.org/10.1016/j.techfore.2021.121110

Hummels, H., & Argyrou, A. (2021). Planetary demands: Redefining sustainable development and sustainable entrepreneurship. *Journal of Cleaner Production*, *278*, Article 123804. https://doi.org/10.1016/j.jclepro.2020.123804

Hussain, H. I., Slusarczyk, B., Kamarudin, F., Thaker, H. M. T., & Szczepańska-Woszczyna, K. (2020). An investigation of an adaptive neuro-fuzzy inference system to predict the relationship among energy intensity, globalization, and financial development in major ASEAN economies. *Energies*, *13*(4), Article 850. https://doi.org/10.3390/en13040850

International Energy Agency. (2021). *World energy outlook 2021*. https://www.iea.org/reports/world-energy-outlook-2021

Johnson, M. P., & Schaltegger, S. (2020). Entrepreneurship for sustainable development: A review and multilevel causal mechanism framework. *Entrepreneurship Theory and Practice*, *44*(6), 1141–1173. https://doi.org/10.1177/1042258719885368

Jorgenson, A. K., Alekseyko, A., & Giedraitis, V. (2014). Energy consumption, human well-being and economic development in central and eastern European nations: A cautionary tale of sustainability. *Energy Policy*, 66, 419–427. https://doi.org/10.1016/j.enpol.2013.11.020

Kazi, S., Husain, S., Hammoudeh, S., & Omar, N. (2021). Innovation, militarization, and renewable energy and green growth in OECD countries. *Environmental Science and Pollution Research International*, *28*, 36004–36017. https://doi.org/10.1007/s11356-021-13326-6

Khan, A., Muhammad, F., Chenggang, Y., Hussain, J., Bano, S., & Khan, M. A. (2020). The impression of technological innovations and natural resources in energy-growth-environment nexus: A new look into BRICS economies. *Science of the Total Environment*, *727*, Article 138265. https://doi.org/10.1016/j.scitotenv.2020.138265

Khattak, S. I., Ahmad, M., Khan, Z. U., & Khan, A. (2020). Exploring the impact of innovation, renewable energy consumption, and income on CO2 emissions: New evidence from the BRICS economies. *Environmental Science and Pollution Research*, *27*, 13866–13881. https://doi.org/10.1007/s11356-020-07876-4

Khattak, S. I., Ahmad, M., ul Haq, Z., Shaofu, G., & Hang, J. (2022). On the goals of sustainable production and the conditions of environmental sustainability: Does cyclical innovation in green and sustainable technologies determine carbon dioxide emissions in G-7 economies. *Sustainable Production and Consumption*, *29*, 406–420. https://doi.org/10.1016/j.spc.2021.10.022

Knoppen, D., & Knight, L. (2022). Pursuing sustainability advantage: The dynamic capabilities of born sustainable firms. *Business Strategy and the Environment*, *31*(4), 1789–1813. https://doi.org/10.1002/bse.2984

Kun, Z. (2024). Towards achieving sustainable development in China: What role does digital technologies and green technologies play? *Engineering Economics*, *35*(2), 222–235. https://doi.org/10.5755/j01.ee.35.2.33422

Lee, C. C., Xing, W., Wu, W., & Lee, C. C. (2023). Export diversification and the green economy: The key role of economic risk. *Technological and Economic Development of Economy*, *29*(2), 717–740. https://doi.org/10.3846/tede.2023.18532

Li, B., & Haneklaus, N. (2022). The role of clean energy, fossil fuel consumption and trade openness for carbon neutrality in China. *Energy Reports*, *8*, 1090–1098. https://doi.org/10.1016/j.egyr.2022.02.092

Lin, B., & Ma, R. (2022). Green technology innovations, urban innovation environment and CO_2 emission reduction in China: Fresh evidence from a partially linear functional-coefficient panel model. *Technological Forecasting and Social Change*, *176*, Article 121434. https://doi.org/10.1016/j.techfore.2021.121434

Liu, H., Wong, W. K., Cong, P. T., Nassani, A. A., Haffar, M., & Abu-Rumman, A. (2023). Linkage among urbanization, energy consumption, economic growth and carbon emissions. Panel data analysis for China using ARDL model. *Fuel*, *332*, Article 126122. https://doi.org/10.1016/j.fuel.2022.126122

Lüdeke-Freund, F. (2020). Sustainable entrepreneurship, innovation, and business models: Integrative framework and propositions for future research. *Business Strategy and the Environment*, *29*(2), 665–681. https://doi.org/10.1002/bse.2396

Luo, Y., Salman, M., & Lu, Z. (2021). Heterogeneous impacts of environmental regulations and foreign direct investment on green innovation across different regions in China. *Science of the Total Environment*, *759*, Article 143744. https://doi.org/10.1016/j.scitotenv.2020.143744

Maldonado-Bautista, I., Klein, P. G., & Artz, K. W. (2023). The role of political values and ideologies of entrepreneurs and financiers. *Entrepreneurship Theory and Practice*, *47*(1), 172–205. https://doi.org/10.1177/10422587211010496

Meirun, T., Makhloufi, L., & Ghozali Hassan, M. (2020). Environmental outcomes of green entrepreneurship harmonization. *Sustainability*, *12*(24), Article 10615. https://doi.org/10.3390/su122410615

Méndez-Picazo, M. T., Galindo-Martín, M. A., & Castaño-Martínez, M. S. (2021). Effects of sociocultural and economic factors on social entrepreneurship and sustainable development. *Journal of Innovation & Knowledge*, *6*(2), 69–77. https://doi.org/10.1016/j.jik.2020.06.001

Mol, A. P. J., & Spaargaren, G. (2000). Ecological modernisation theory in debate: A review. *Environmental Politics*, *9*(1), 17–49. https://doi.org/10.1080/09644010008414511

Muñoz, P., & Cohen, B. (2018). Sustainable entrepreneurship research: Taking stock and looking ahead. *Business Strategy and the Environment*, *27*(3), 300–322. https://doi.org/10.1002/bse.2000

Naeem, M. A., Raza Rabbani, M., Karim, S., & Billah, S. M. (2023). Religion vs ethics: Hedge and safe haven properties of Sukuk and green bonds for stock markets pre-and during COVID-19. *International Journal of Islamic and Middle Eastern Finance and Management*, *16*(2), 234–252. https://doi.org/10.1108/imefm-06-2021-0252

Nazir, R., Gillani, S., & Shafiq, M. N. (2023). Realizing direct and indirect impact of environmental regulations on pollution: A path analysis approach to explore the mediating role of green innovation in G7 economies. *Environmental Science and Pollution Research*, *30*, 44795–44818. https://doi.org/10.1007/s11356-023-25399-6

Neumann, T. (2021). Does it pay for new firms to be green? An empirical analysis of when and how different greening strategies affect the performance of new firms. *Journal of Cleaner Production*, *317*, Article 128403. https://doi.org/10.1016/j.jclepro.2021.128403

Nigg-Stock, A., Bayrle, N., & Brecht, L. (2023). Drivers of exploitative and explorative innovation efficiency. *Digital Business*, *3*(2), Article 100062. https://doi.org/10.1016/j.digbus.2023.100062

Obobisa, E. S., Chen, H., & Mensah, I. A. (2022). The impact of green technological innovation and institutional quality on CO_2 emissions in African countries. *Technological Forecasting and Social Change*, *180*, Article 121670. https://doi.org/10.1016/j.techfore.2022.121670

Organisation for Economic Co-operation and Development. (2021). *A green recovery*: *Rethinking the built environment and transport*. *Green Growth and Sustainable Development Forum*. https://www.oecd.org/en/events/2021/11/a-green-recovery-rethinking-the-built-environment-and-transport.html

Omri, A. (2018). Entrepreneurship, sectoral outputs and environmental improvement: International evidence. *Technological Forecasting and Social Change*, *128*, 46–55. https://doi.org/10.1016/j.techfore.2017.10.016

Porter, M. E., & van der Linde, C. (1995). Toward a new conception of the environment-competitiveness relationship. *Journal of Economic Perspectives*, *9*(4), 97–118. https://doi.org/10.1257/jep.9.4.97

Rybski, R. (2023). Energy in the European Green Deal: Impacts and recommendations for MENA countries. *The Journal of World Energy Law* & *Business*, *16*(2), 127–142. https://doi.org/10.1093/jwelb/jwac033

Schumpeter, J. A. (2017). *Essays*: *On entrepreneurs*, *innovations*, *business cycles and the evolution of capitalism* (1st ed.). Routledge. https://doi.org/10.4324/9781351311489

Shahid, M. N., & Sattar, A. (2017). Behavior of calendar anomalies, market conditions and adaptive market hypothesis: Evidence from Pakistan stock exchange. *Pakistan Journal of Commerce and Social Sciences* (*PJCSS*), *11*(2), 471–504.

Shahid, M. N., Coronado, S., & Sattar, A. (2019). Stock market behaviour: Efficient or adaptive? Evidence from the Pakistan Stock Exchange. *Afro-Asian Journal of Finance and Accounting*, *9*(2), 167–192. https://doi.org/10.1504/aajfa.2019.099488

Shao, X., Zhong, Y., Liu, W., & Li, R. Y. M. (2021). Modeling the effect of green technology innovation and renewable energy on carbon neutrality in N-11 countries: Evidence from advanced panel estimations. *Journal of Environmental Management*, *296*, Article 113189. https://doi.org/10.1016/j.jenvman.2021.113189

Shepherd, D. A., & Patzelt, H. (2011). The new field of sustainable entrepreneurship: Studying entrepreneurial action linking "what is to be sustained" with "what is to be developed". *Entrepreneurship Theory and Practice*, *35*(1), 137–163. https://doi.org/10.1111/j.1540-6520.2010.00426.x

Song, M., Yang, M. X., Zeng, K. J., & Feng, W. (2020). Green knowledge sharing, stakeholder pressure, absorptive capacity, and green innovation: Evidence from Chinese manufacturing firms. *Business Strategy and the Environment*, *29*(3), 1517–1531. https://doi.org/10.1002/bse.2450

Streimikis, J., Ślusarczyk, B., Siksnelyte-Butkiene, I., & Mura, L. (2024). Development of circular economy in the Visegrad group of countries. *Contemporary Economics*, *18*(2), 365–375. https://doi.org/10.5709/ce.1897-9254.543

Streimikiene, D., & Mikalauskiene, A. (2023). Assessment of agricultural sustainability: Case study of Baltic states. *Contemporary Economics*, *17*(2), 128–141. https://doi.org/10.5709/ce.1897-9254.503

Sun, H., Edziah, B. K., Sun, C., & Kporsu, A. K. (2019). Institutional quality, green innovation and energy efficiency. *Energy Policy*, *135*, Article 111002. https://doi.org/10.1016/j.enpol.2019.111002

Tang, Y., Zhu, H., & Yang, J. (2022). The asymmetric effects of economic growth, urbanization and deindustrialization on carbon emissions: Evidence from China. *Energy Reports*, *8*, 513–521. https://doi.org/10.1016/j.egyr.2022.05.076

Trapp, C. T. C., & Kanbach, D. K. (2021). Green entrepreneurship and business models: Deriving green technology business model archetypes. *Journal of Cleaner Production*, *297*, Article 126694. https://doi.org/10.1016/j.jclepro.2021.126694

United Nations. (2015). *Transforming our world*: *The 2030 agenda for sustainable development* (A/RES/70/1). United Nations General Assembly. https://docs.un.org/en/A/RES/70/1

Venâncio, A., & Pinto, I. (2020). Type of entrepreneurial activity and sustainable development goals. *Sustainability*, *12*(22), Article 9368. https://doi.org/10.3390/su12229368

Verkaart, S., Mausch, K., Claessens, L., & Giller, K. E. (2019). A recipe for success? Learning from the rapid adoption of improved chickpea varieties in Ethiopia. *International Journal of Agricultural Sustainability*, *17*(1), 34–48. https://doi.org/10.1080/14735903.2018.1559007

Vuorio, A. (2017). Young adults and sustainable entrepreneurship: The role of culture and demographic factors. *Journal for International Business and Entrepreneurship Development*, *10*(3), 209–230. https://doi.org/10.1504/jibed.2017.085499

Wani, M. J. G., Loganathan, N., & Esmail, H. A. H. (2024). Impact of green technology and energy on green economic growth: Role of FDI and globalization in G7 economies. *Future Business Journal*, *10*, Article 43. https://doi.org/10.1186/s43093-024-00329-1

Wang, C. H., & Juo, W.-J. (2021). An environmental policy of green intellectual capital: Green innovation strategy for performance sustainability. *Business Strategy and the Environment*, *30*(7), 3241–3254. https://doi.org/10.1002/bse.2800

Wang, M., Li, Y., Li, J., & Wang, Z. (2021). Green process innovation, green product innovation and its economic performance improvement paths: A survey and structural model. *Journal of Environmental Management*, *297*, Article 113282. https://doi.org/10.1016/j.jenvman.2021.113282

Wang, W., Li, Y., Lu, N., Wang, D., Jiang, H., & Zhang, C. (2020). Does increasing carbon emissions lead to accelerated eco-innovation? Empirical evidence from China. *Journal of Cleaner Production*, *251*, Article 119690. https://doi.org/10.1016/j.jclepro.2019.119690

Wang, Z., & Zhu, Y. (2020). Do energy technology innovations contribute to CO_2 emissions abatement? A spatial perspective. *Science of the Total Environment*, *726*, Article 138574. https://doi.org/10.1016/j.scitotenv.2020.138574

Weis, L., & Nikolić, G. (2024). Discussing the role of innovation in green entrepreneurship and development. In A. Grigorescu, & J. V. Andrei (Eds.), *Entrepreneurship and development for a green resilient economy* (*lab for entrepreneurship and development*) (pp. 1–21). Emerald. https://doi.org/10.1108/978-1-83797-088-920241001

Wiebe, K. S. (2022). A global perspective on sustainable development. In J. Murray, A. Owen, M. Simas, & A. Malik (Eds.), *A triple bottom line analysis of global consumption* (pp. 3–11). Jenny Stanford Publishing. https://doi.org/10.1201/9781003256885-2

Yang, J., Cai, W., Ma, M., Li, L., Liu, C., Ma, X., Li, L., & Chen, X. (2020). Driving forces of China's CO_2 emissions from energy consumption based on Kaya-LMDI methods. *Science of the Total Environment*, *711*, Article 134569. https://doi.org/10.1016/j.scitotenv.2019.134569

Yikun, Z., Woon Leong, L., Cong, P. T., Abu-Rumman, A., Al Shraah, A., & Hishan, S. S. (2023). Green growth, governance, and green technology innovation. How effective towards SDGs in G7 countries? *Economic Research – Ekonomska istraživanja*, *36*(2), Article 2145984. https://doi.org/10.1080/1331677x.2022.2145984

York, J. G., & Venkataraman, S. (2010). The entrepreneur-environment nexus: Uncertainty, innovation, and allocation. *Journal of Business Venturing*, *25*(5), 449–463. https://doi.org/10.1016/j.jbusvent.2009.07.007

You, W., Zhang, Y., & Lee, C.-C. (2022). The dynamic impact of economic growth and economic complexity on CO_2 emissions: An advanced panel data estimation. *Economic Analysis and Policy*, *73*, 112–128. https://doi.org/10.1016/j.eap.2021.11.004

Youssef, A. B., Boubaker, S., & Omri, A. (2018). Entrepreneurship and sustainability: The need for innovative and institutional solutions. *Technological Forecasting and Social Change*, *129*, 232–241. https://doi.org/10.1016/j.techfore.2017.11.003

Yuan, X., Su, C.-W., Umar, M., Shao, X., & Lobonţ, O. R. (2022). The race to zero emissions: Can renewable energy be the path to carbon neutrality? *Journal of Environmental Management*, *308*, Article 114648. https://doi.org/10.1016/j.jenvman.2022.114648

Yumashev, A., Ślusarczyk, B., Kondrashev, S., & Mikhaylov, A. (2020). Global indicators of sustainable development: Evaluation of the influence of the human development index on consumption and quality of energy. *Energies*, *13*(11), Article 2768. https://doi.org/10.3390/en13112768

Zhang, R. J., Tai, H. W., Cao, Z. X., Wei, C. C., & Cheng, K. T. (2024). Green innovation ecosystem evolution: Diffusion of positive green innovation game strategies on complex networks. *Journal of Innovation & Knowledge*, *9*(3), Article 100500. https://doi.org/10.1016/j.jik.2024.100500